DOES SAMOA HAVE A FUTURE IN RENEWABLE ENERGY?

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2010

DECLARATION

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ABSTRACT

Energy is critical to the economic growth and social development of any country. Samoa, as a least developing country, therefore needs to ensure that its energy demands are supplied for. However, such a demand has risen exponentially in the last few years forcing Samoa to rely heavily on costly imported fossil fuels such as diesel and petroleum.

The motivation to undertake this research on Samoa is due to the fact that the price of fossil fuel products especially petrol and diesel among others, fluctuates as they are dictated by the market prices overseas. Moreover, these products are imported from halfway around the world which increases the prices of all fossil fuel products by the time they land on Samoan soil. This in turn increases the cost of all other necessities such as electricity, water and food. So there is an urgent need to develop and apply technologies which will enable Samoa to use its abundant renewable energy sources in the most efficient ways, while at the same time reducing its heavy dependence on overpriced imported fossil fuels.

This Dissertation concentrates on the currently abundant renewable resources in Samoa as well as touching on potential sources. The abundant renewable and widely used resources in Samoa at present include biomass, hydropower and solar energy. Promising potential sources are wind, geothermal and wave energy. This dissertation presents current renewable energy projects being undertaken by the Samoan government such as solar electricity on Apolima Island, wind resource assessment and feasibility studies, hydropower for electricity-production, biomass use in its solid and liquid forms in Samoa. The results and rates of development as well as relevant usage of these projects of these projects in the Samoan context, will differ from one renewable source to another. Also included in this report are ongoing researches and trials being carried out such as the use of biodiesel from coconut to substitute fossil fuel in electricity production and transport. With regards to utilizing other renewable energy sources available in Samoa such as geothermal and wave energy, this dissertation will also determine if they are worthwhile projects or not. The results collated by this research determine the most viable, cost-effective and efficient renewable energy technology that Samoa should undertake to ensure that its energy needs are always satisfied.

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ACKNOWLEDGMENTS

Much appreciated is the information provided by the following people on renewable energy in Samoa. Thank you very much for taking the time to send the information requested.

Dr. Taema Imo-Seuoti	–	Senior Lecturer, Faculty of Science, National University of Samoa (NUS)
Mrs Kuinimeri Asora Finau	–	Scientific Research Organisation of Samoa (SROS) Assistant Chief Executive Officer
Mrs Lilian Penaia–Faasoa	–	Land & Transport Authority (LTA) Renewable Energy Officer
Mr Wairarapa Young	–	Electric Power Corporation (EPC) Renewable Energy Officer

Undertaking studies for a Master of Science in Renewable Energy, culminating in this dissertation, would not have been possible without the financial assistance from the Government of Samoa.

Thank you also to the Faasoa Family, Chan Ting Family, my husband Joseph along with our two beautiful children Lenalei Daijimara & Oliver Cepha for all your support and encouragement.

INTRODUCTION

The oil crisis of the 1970s prompted the major industrial countries and energy companies worldwide to search for energy alternatives because energy is central to the economic development of any country. This led to a boost in research and development as well as investment in the renewable energy industry in search of ways to meet energy demands and to reduce dependency on fossil fuels. By the 1990s, it was obvious that using renewable energy was more environmentally-friendly than fossil fuels because they do not emit greenhouse gases which were found to have detrimental effects on the ozone layer (Boyle, 2004). Renewable energy is clean and can be replenished by nature. It can be harnessed to provide such services as electricity, transport, heating and cooling, to name a few. The International Renewable Energy Agency (IRENA) strongly believes that the use of renewable energy will increase dramatically over the coming years due to the vital role it plays in enhancing energy security, reducing greenhouse gas emissions and combating climate change, alleviating energy poverty, supporting sustainable development as well as boosting economic growth (IRENA, 2010).

Samoa is an island nation in the South Pacific with a latitude of 13^{o} 35S and longitude 172^{o} 20W (Central Intelligence Agency (CIA), 2010).

Figure 1: Map of Samoan Islands and its location in the Pacific
(Source: SPREP, 2004)

It has a population of about 185,000 and land area 284,176 hectares (Samoa Bureau of Statistics, 2008). This country of small islands can be found close to the equator and enjoys a warm tropical climate of an average of 27^oC throughout the year. Samoa's geographical location ensures an abundant supply of sunlight as well as windy conditions along the coastal areas. Based on these facts, solar and wind energy can therefore be the 'free' sources of energy Samoa can harness to satisfy most of its energy needs rather than depending totally on fossil fuels. A cleaner option for producing electricity needs to be the alternative to the high demand for petroleum and diesel. The answer may lie in the solar & wind energies. This will be in line with the Samoa National Energy Policy of "increasing the share of mass production from renewable sources to 20% by year 2030" and to "increase the contribution of Renewable Energy for energy services and supply by 20% by year 2030" (Ministry of Finance (MOF), 2009). In addition to solar and wind as renewable energy sources for Samoa, others include geothermal, biofuel, biogas, waste and wave to a lesser extent hold potential for future renewable energy development projects.

Currently utilized in Samoa are biomass, solar heating, solar power and hydropower and coconut oil (CNO) biofuel blends for electricity production. Dominating the renewable energy consumption by sources, is biomass at 90.12%, followed by hydro-electricity at 9.33% and trailing are CNO biofuel and solar at 0.41% and 0.14% respectively (MOF, 2010).

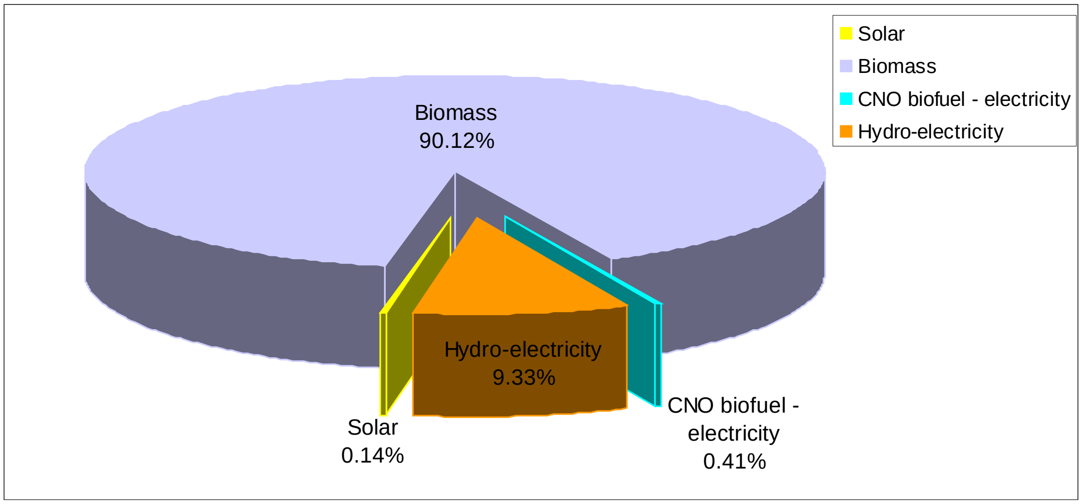


Figure 2: Comparison of Renewable Energy Consumption in Samoa by Source

Also undergoing trial stages in Samoa is the use of bio-diesel fuel to run vehicles. Electricity generation, transmission and distribution are exclusively under the authority of the Electric Power Corporation (EPC) which is a monopolized government-owned company (MOF, 2009). The island of Apolima with a 100 residents is being powered by PV solar panels. This was a solution provided by the sole electricity provider on island, EPC, to problems of having to transfer diesel daily or even weekly, to Apolima Island by small alia fishing boats. Results from this project will greatly assist in the corporation's efforts in implementing their Photovoltaic Rural Electrification Programme. EPC has also tried different blends of coconut oil with diesel to run its electricity generators. Furthermore, EPC and the Scientific Research Organisation of Samoa (SROS) have experimented with biofuel from coconut oil as an alternative fuel for their respective cars. In addition, EPC and others have been conducting wind resource assessments and feasibility studies based on the results from several wind masts erected at a few chosen sites to determine the availability and feasibility of wind as an energy source. Some families already have solar hot water systems mounted on top of their homes to take advantage of free solar energy.

Increasing income among families has meant increasing purchasing power so families are able to afford more expensive choices in transportation, electrical appliances, lighting and cooking thus increasing the demand for fossil fuel. Petroleum dominates the total primary energy usage in Samoa with 65.5% followed by biomass at 31.1%, hydropower at 3.2% and the rest provided by coconut biofuel and solar at 2% and 1% respectively (Ministry of Finance (MOF), 2010). This information is illustrated by Fig 2 and it clearly shows that Samoa is heavily reliant on pricey imported fossil fuels. The figures were based on an estimated consumption of 118.1 kilo-tonnes of oil equivalent, according to the Ministry of Finance (2010).

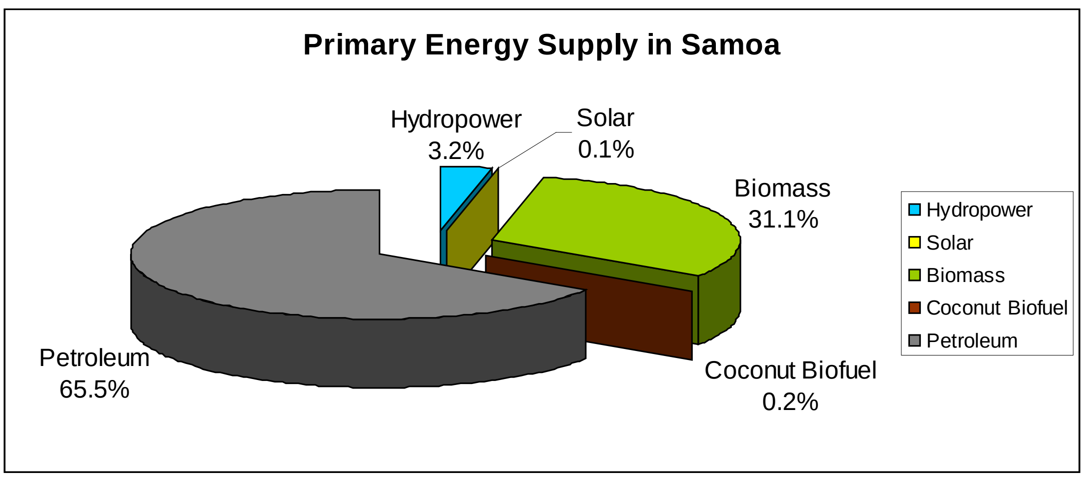


Fig 3: Total Primary Energy Supply in Samoa

Hydropower has been used extensively in Samoa since 1959 (EPC, 2007) to provide electricity and currently supplies about 40% of the total electricity production in Samoa, largely to the main grid on the island of Upolu Island, home to approximately three-quarters of the total Samoan population. Petroleum is mainly used by the transport sector especially with the increase in the number of right-hand-drive (RHD) cars being imported into Samoa at present, in addition to left-hand-drive (LHD) cars, since the road switch in September 2009. Biomass, in the form of firewood, coconut shells and husks, plant waste residues and wood charcoal, is mainly used for domestic cooking.

A breakdown of the energy consumption in each sector is shown in Table 1 which clearly shows that the Transport sector is a major energy consumer with an increase of 15% in consumption from 2008 to 2009, due to the influx of RHD cars prior to and following the road switch in September 2009.

Table 1: Energy Consumption per Sector (MOF)

		Total Energy Consumption (kilo-tonne of oil equivalent)				
Types of Energy	**Sector**	**1981**	**2000**	**2007**	**2008**	**2009**
Biomass	Commercial	41	18.1	2.1	2.2	1.3
	Residential		35.5	33.8	34.3	35.4
Petroleum	Electricity	6.8	12.3	16	15.8	18.92
	Transport	14.6	26.5	44.9	44.0	51.69
	Commercial	1.0	16.5	8.5	6.7	5.36
	Residential	2.1	1.1	1.9	1.2	0.01
	Agriculture, Forestry & Fishing	–	–	–	–	1.36
Electricity	Hydropower	0.6	3.2	4.4	3.8	3.8
	Coconut Bio-fuel	–	–	–	–	0.2
	PV	–	–	–	0.001	0.001
Others	Solar	–	–	0.04	0.04	0.06
TOTAL		**66.10**	**113.20**	**111.64**	**108.04**	**118.10**

Figure 2 and Table 1 clearly indicate a need to transform the energy industry from one heavily reliant on fossil fuels to one which harnesses renewable energy sources freely available on island. However, the initial cost of setting up such systems as solar and wind may not be afforded by a typical Samoan family as the minimum wage an hour is still only SAT[1] $2

[1] SAT stands for the Samoan Tala (Samoan currency)

(approximately AUS[2] $0.89). Most families depend heavily on remittances from their relatives overseas which are mainly spent on church, family and school commitments. Only a small percentage of families may be able to purchase and install solar and wind systems. This leaves the sole electricity provider, Electricity Power Corporation (EPC) to look for new ways and projects of producing power from renewable sources so the bill surcharges do not increase every month as is the current practice, which is a direct result of the ever increasing costs of fossil fuels like petrol and diesel.

The motivation to undertake this research on Samoa is due to the fact that the price of fossil fuel products especially petrol and diesel among others, fluctuates as they are dictated by the market prices overseas. Moreover, these products are imported from halfway around the world which increases the prices of all fossil fuel products by the time they land on Samoan soil. This in turn increases the cost of all other necessities such as electricity, water and food. As a result, Samoans are struggling to cope with the high standard of living as it is. So there is an urgent need to develop and apply technologies which will enable Samoa to use its abundant renewable energy sources in the most efficient ways, simultaneously letting go of its heavy dependence on costly imported fossil fuels.

[2] AUD stands for the Australian Dollar (Australian currency)

Some of the key questions this dissertation will aim to find answers to are:

1) What is an estimation of how much renewable resource is available?

2) What are the existing renewable energy systems?

3) What are the best “suitable” systems for the Samoan setting?

4) How viable / affordable are these systems in the Samoan context?

5) If not, is there any funding available for such initiatives as renewable energy in smaller ‘least developing’ countries like Samoa?

LITERATURE REVIEW

Renewable Energy

The renewable energy sources, derived primarily from the enormous power of the radiation from the sun are at once the most ancient and the most modern forms of energy used by humanity (Boyle, 2004). The International Renewable Energy Agency (IRENA) believes that abundant, untapped renewable energy sources worldwide can make an immense contribution to the world’s fast growing demand for energy, especially when the global population is projected to reach 10 billion by year 2050 (IRENA, 2010). Renewable energy sources can make significant contributions to the diversity and security of energy supply, to economic development and to addressing local environmental pollution (IEA, 2006). Renewable energies, according to the World Energy Council (WEC), have considerable potential and could theoretically provide a nearly unlimited supply of relatively clean and mostly local energy (WEC, 2003) especially for developing countries like Samoa where Samoa’s geographical location of latitude 13^{o} 35S and longitude 172^{o} 20W (CIA, 2010) has several advantages for extensive use with regards to the availability of solar and wind resources. Renewable energy could provide an alternative to the expensive grid extensions to isolated areas and the use of costly imported fossil fuels. Conditions in the Pacific Islands such as their remote locations, small demand as well as the high costs of fossil fuel imports all make renewable sources of energy the most attractive option for these countries (Yu & Taplin, 1998). Fossil fuel imports typically make up the single most costly import item in the Pacific Island countries (Yu & Taplin, 1998). A report by the Australian Government's overseas aid program, AusAID (2001) on 'Renewable Energy in Developing Countries' renders support to this notion, in stating that renewable energy can be particularly appropriate for developing countries especially the rural areas and remote locations where the transmission and distribution of energy from fossil fuels can be difficult and expensive, so exploiting local renewable energy sources would offer a viable alternative. The high cost of fuel has been reported to be the main driving force behind the Pacific Island countries turning to alternative renewable energy sources (People's Online Daily, 2008). Moreover, the United States Department of Energy through a report by its National Renewable Energy Laboratory (NREL) realizes that money spent on importing energy is considered to be lost money because every dollar spent on imports is a dollar lost from the local economy (NREL, 1997) and the Pacific Island developing countries need to retain as much dollars as possible to improve their respective economies. Because many islands depend on imported oil for all their energy needs, island populations are faced with some of the highest costs of electricity in the world due to the combination of increasing oil prices and shipping costs (NREL, 2010).

Energy is central to the economic development of any country and there is a clear correlation between energy consumption and living standards (AusAID, 2001). It is also known that the international community has long been aware of the close relationship between development and access to modern energy services (International Energy Agency (IEA), 2010). Lack of access to such modern energy services as electricity and clean cooking facilities, is a serious hindrance to social and economic development (IEA, 2010). More than a billion people who live in developing countries, many in rural areas or in isolated communities do not have any access to energy and their poor living conditions and low prospects in life are considered to be caused by this energy poverty (WEC, 2003). According to IEA (2010), about 1.4 billion or 20% of the global population lack access to electricity and 2.7 billion or 40% of the global population still rely on the traditional use of biomass for cooking, including Samoa. As reported by People's Daily Online (2008), the Pacific Islands Greenhouse Gas Abatement through Renewable Energy Project (PIGGAREP) found that 70% of the total population of all Pacific Islands has no access to electricity. Being able to harness the available renewable energy sources will greatly improve the livelihoods of the people in developing countries. Benefits will include economic and social development from access to electricity, health benefits from access to clean energy for heating and cooking, income generation for local communities, capacity building, local employment and expertise (WEC, 2003). This is where 'technology transfer' can play an important role because local training ensures that local people can make additional use of their skills by opening up local businesses (AusAID, 2001). NREL (1997) concurs that indigenous renewable energy sources represent a secure and stable source of energy, a potential source of jobs and economic development as well as reductions in utility bills for not only individuals but also companies and whole communities. The renewable energy industry provides a wide range of employment opportunities, from high-tech manufacturing of photovoltaic components to maintenance jobs at wind power plants (NREL, 1997) to small home-based businesses with extended working hours because of the availability of electricity from renewable sources. The Pacific Island countries are gradually changing from subsistence economies to monetary systems and this is accompanied by an increase in the demand for energy, especially electricity which has many beneficial uses and has steadily provided an improvement in the standard of living (Yu & Taplin, 1998). However, access to renewable energy alone will not alleviate poverty in the developing countries if it is only seen as an energy issue rather than a development issue because renewable energy needs to be linked with, or be part of another project which improves development in order to achieve economic development (AusAID, 2001).

Despite the fact that renewable energy systems represent the most environmentally friendly and cost-effective means of providing electricity to rural communities in developing countries, it has been a relatively slow process (Urmee, Harries & Schlapfer, 2009) because in developing countries with inadequate capacity, it is vital to consider that renewables, being primarily domestic fuels, should be treated on a case-by-case basis because their feasibility and true costs depend on local circumstances (WEC, 2003). Due to the diverse nature of renewable sources, each country or region must promote technologies and options best suited to its own needs and resources (IEA, 2006). It must be the appropriate technology which can easily be adapted to the needs of the target community because simply taking hardware for renewable energy from a developed country like Australia and putting it in a developing island like Samoa has a high chance of failure (AusAID, 2001). Despite the poor track record thus far, the role of renewable energy will remain significant in the national and regional energy development plans in the Pacific Island Developing States (Rupeni, 2003) such as Samoa because of their distance from the main fossil fuel ports.

Exploiting the technical potential of many renewable sources still has certain limits such as integration with base-load distribution systems, the low capacity factors and lack of storage, so the timeframe for substantial penetration of new renewable technologies in the global energy mix is estimated to be 30–40 years (WEC, 2002). Other current limitations identified as the major impeding issues in the development of renewable energy systems in the South Pacific are the shortages of skilled human resources, inappropriate institutions and scarcity of capital resources (Yu, Gilmour & Taplin, 1996). This was affirmed by South Pacific Applied Geoscience Commission (SOPAC) (Rupeni, 2003) in a report which stated that training programmes on renewable energy in the South Pacific region are often delivered on an ad hoc basis, due to the absence of a long-term training plan for the region and the limited funding dedicated to capacity building in renewable energy. Pacific island countries do have a wide range of training needs in the renewable energy sector, mainly due to a few energy specialists and the difficulty of retaining skilled and qualified personnel in the region because of the higher pay packages offered elsewhere (Rupeni, 2003). Major inhibitors to the widespread use of renewable energy in the Pacific developing countries have been identified as cost and the slow technical progress over the past decades (AusAID, 2001; SPREP, 2004). Yet another contributing factor to the slow progress may be the fact that the energy market in the South Pacific Islands is small and spread over a large area (Asmundsson, 2008).

It is important to recognize the crucial role of governments in ensuring the smooth transition from a system highly dependent on fossil fuels to one which utilizes the available renewable sources. The research, development and demonstration (RD&D) programmes of governments will play a vital role in enabling renewable technologies to deliver their potential (IEA, 2006). Governments can greatly assist the energy industry by complementing private RD&D investments with support for basic research and demonstration of new technologies and by providing adequate protection for intellectual property, increasing cooperation and regional market integration and strengthening competition and trade (WEC, 2003).

Solar Energy

The Sun has been worshipped as a giver of life to the planet since ancient times and the industrial ages provided the inhabitants of Earth with the understanding of sunlight as an energy source (Markvart, 2009). The Sun has an energy flux of very high thermodynamic quality, an accessible source of temperature very much greater than from any conventional engineering source (Twidell & Weir, 2009). On average, the Earth's surface receives about 1.2×10^{17} W of solar power, which means that enough energy is supplied to the Earth in one hour to satisfy the entire energy demand of the human population over the whole year (Markvart, 2009) so Samoa can utilize its solar potential given its ideal geographic location and the abundant amount of solar energy it receives. Solar energy is considered to be the largest renewable source on Earth (IEA, 2006). Solar energy is an abundant energy source which is free, non-polluting and renewable (New Zealand Energy Efficiency and Conservation Authority (EECA), 2010).

The colossal amounts of solar energy received by Earth can be used thermally for heat engines, or more importantly for photochemical and photophysical processes such as photovoltaic (PV) power and photosynthesis (Twidell & Weir, 2009). The Asian Development Bank (ADB) on their web page stated that solar energy is deemed as one of the fastest growing electricity technologies over recent years and is highly significant to the developing countries in Asia and the Pacific regions. Yu & Taplin (1998) revealed that most countries of the Pacific Island nations are near the equator and have abundant solar resources of 2000 – 2500 sunshine hours per year which is an average of five to seven hours per day. Solar energy in these regions is of immense significance because the economies of scale can reduce costs to make solar energy competitive with conventional sources of energy (ADB, 2010). Furthermore, some developing countries have greater solar radiation, more rapidly growing electricity demand, and more availability of land than developed countries (ADB, 2010).

Solar energy can either be used directly or indirectly, using a variety of technologies. Direct uses of solar energy include absorption in solar collectors to provide hot water or space heating as well as enhancing the contribution of solar energy to space heating and lighting requirements of buildings with 'passive solar' designed features (Boyle, 2004). Additionally, solar electricity can be produced from solar energy either in the process of solar thermal, where solar energy can be concentrated by mirrors to provide high-temperature heat for generating electricity or by using solar PV systems which convert sunlight directly into electricity (Boyle, 2004). As well as the above mentioned direct uses of solar energy, some of the prominent indirect uses of solar energy according to Boyle (2004) include hydropower, wind power, wave power and bioenergy. In Samoa, solar energy is mainly used by solar hot water systems for water-heating and solar PV panels to provide electricity as well as drying crops such as cocoa. Indirectly, Samoa enjoys an abundance of solar energy to provide the other types of energy such as hydropower and biomass.

In recent times, solar PV technologies have been promoted as a cost effective means of rural electrification in developing countries especially where lighting is provided by solar home systems (SHS) for poor and remote communities where traditional lighting sources are of poor quality and pose substantial health risks (Dornan, 2010). Because so many people in developing countries lack access to electricity, NREL (1997) reports that the largest market for PV systems is in the developing world where two billion people still do not have electricity in their homes. Dornan (2010) believes that the advantages of SHS over other technologies for rural electrification are highly relevant to all developing South Pacific countries including Samoa. Such advantages of SHS include a generally lower life cycle cost than traditional lighting sources, modular in nature thus making them suitable for rural areas where demand for electricity is variable and where irregular and unreliable transportation poses a problem for the transport of traditional fuels (Dornan, 2010). In spite of this, several barriers to the diffusion of SHS in the developing island countries were found to include the high upfront costs (IEA, 2006; Markvart, 2009; Dornan, 2010) and the technical problems where systems are not well-maintained and eventually break down (Dornan, 2010). The high upfront costs often make SHS unaffordable for rural households which is worsened by the lack of a savings culture (Dornan, 2010), as is the case in Samoa. Despite these setbacks, Markvart (2009) recognizes that PV is the most competitive of systems when small amounts of energy are required but people are far from the grid. This is because PV systems have no fuel costs, low maintenance costs as well as low replacement costs due to their high reliability (Markvart, 2009).

The global installed capacity of PV amounted to 110 MW in 1992 and was amplified to 1809 MW in 2003 (IEA, 2006). About 4000 household solar PV systems of two to eight panels had been installed in the Pacific Islands region for lighting, refrigeration, water pumping, communication and other purposes and were found to be successful in isolated rural areas and outer islands (Yu & Taplin, 1998). A 40 kW solar PV system, installed on the roof of the largest football stadium in one of the Pacific Islands, Tuvalu provided 5% of the city's power demand and reduced imported fuel by 17,000 L with reductions of 50 tCO_2 in carbon emissions after one year of operation (IEA, 2009).

Solar heat, according to an IEA (2006) report, is the logical successor of oil and gas used for heating. Solar water heating, including pool heating, has been commercially available for more than 3 decades (IEA, 2006). Solar hot water systems have been used to a considerable extent in the Pacific Islands region on a commercial basis (Yu & Taplin, 1998) mostly to supply hot water for hotels and small businesses who can afford them, as well as reducing their overall utility bills. Solar heating in Samoa refers to solar water heaters mounted on rooftops as well as solar heat used for pool heating and drying crops such as cocoa or copra.

Wind Energy

Consistent trade winds, as indicated by Figure 3, are an excellent source of energy in the Pacific islands (NREL, 2010) so Samoa being very close to the equator has a lot of potential for wind power. The local wind resource varies considerably with terrain and natural and physical obstructions (IEA, 2009) of the different sites, which is why wind assessments are still being carried out in different parts of Upolu and Savaii Islands in Samoa.

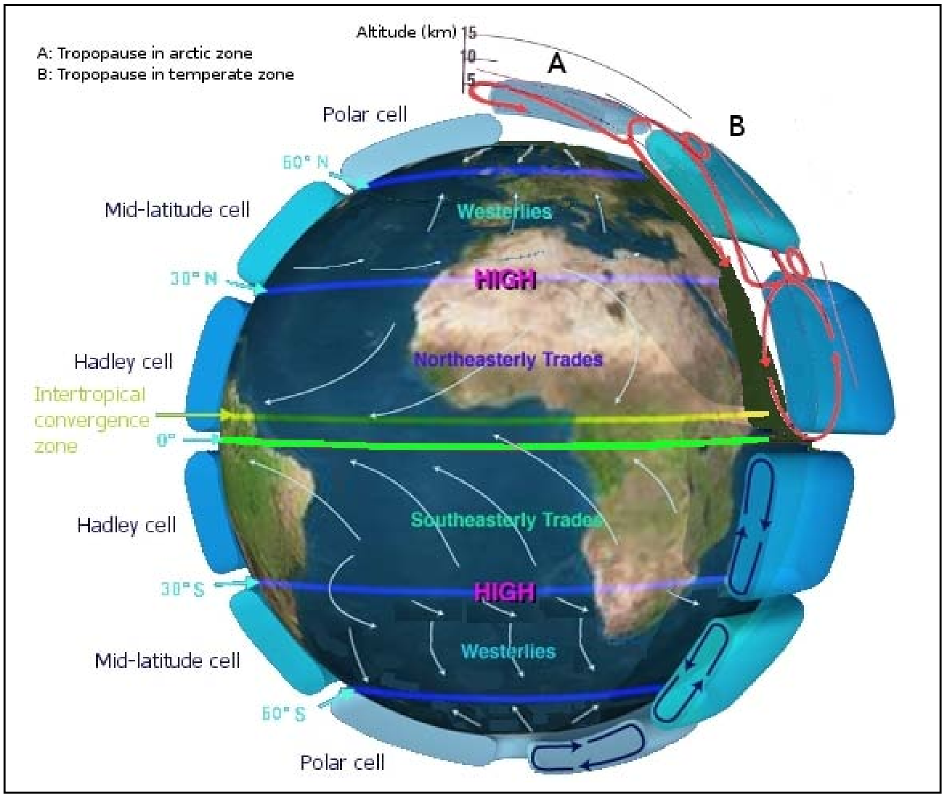


Figure 4: Global Circulation of Wind over the Earth
(Source: http://upload.wikimedia.org/wikipedia)

According to the European Renewable Energy Council (EREC) and Boyle (2004), wind energy is now a mainstream source of electricity, a massive indigenous power source which will never run out and is available for free. Roarty (2000) discovered that new grid electricity generation from wind turbines is gradually becoming competitive with conventionally-fuelled systems in many areas of the world and could be the cheapest form of purely fuel-free renewable electricity production not only in Australia but the whole world. Other advantages of wind energy include the production of 'clean energy' as it does not produce any greenhouse emissions, its low cost which can be competitive with nuclear, coal and gas on a level playing field, 'security of supply' as it does not rely on imported fuel and can easily be deployed where there is sufficient wind available (EREC, 2010). Furthermore, the rapidly increasing wind energy industry has provided local communities with an expanding source of sustainable jobs as well as revenue generated from taxes paid (NREL, 1997; EREC, 2010). In the state of California, USA, its wind industry pays more than $31 million each year in salaries to its employees and contributes to the local economy by paying around $6.7 million in property taxes (NREL, 1997). The European wind power industry employed around 192,000 people and created investments of €13 billion in 2009 (EREC, 2010). Furthermore wind power saves Europe €6 billion in avoided CO_2 costs (EREC, 2010) which means that wind energy can drive down electricity prices in the future, if it is not already doing so now.

Wind energy is expected to continue its strong growth now experienced for many years, as witnessed in some of the well-established markets such as Denmark, Germany, Greece, Sweden and the United States (IEA, 2006). A total of 31 GW[3] of wind generating capacity was installed by

[3] GW stands for gigawatt (10^9 W)

the end of 2002, implying an average growth rate of around 40% per annum since 1997 (Taylor, 2004). At the end of 2004, the global wind capacity reached 47.5 GW and was estimated that wind generated approximately 67 TWh[4] of electricity in 2003 (IEA, 2006). As of July 2010, wind made up more than 490 MW[5] which was almost 5% of New Zealand's total electricity supply in the final quarter of 2009 (EECA, 2010). The cost of wind-generated electricity in Norway, USA, New Zealand, Ireland, Greece and Finland, has fallen steadily over the past two decades due largely to technological development, increased production levels and the use of larger machines (IEA, 2006).

The intermittent nature of wind does not necessarily make it an unreliable resource. In fact, it is for this very reason that wind has to be part of a diverse electricity generation mix so that other resources can stand-in when the wind is not blowing (EECA, 2010).

Hydropower

Hydropower is one of the oldest renewable energy systems (IEA, 2009) and is an indirect manifestation of solar power which is already a major contributor to the world's energy supply (Ramage, 2004). A significant portion of the world's renewable energy supply is already being provided by hydropower with almost half of the electricity production from renewable

[4] TWh stands for terawatt hour (10^{12} Wh)
[5] MW stands for megawatt (10^{6} W)

sources as hydroelectricity (IEA, 2006; Twidell & Weir, 2009). It is already a highly efficient and affordable technology in terms of investment cost and internal rate of return, and its longevity is guaranteed (EREC, 2010). In addition, hydroelectricity produces no greenhouse gas emissions and electricity can be produced from water stored at short notice, making it an excellent complement to intermittent sources of renewable energy such as wind (EECA, 2010). The power of water has been harnessed by civilization for centuries and many small hydropower plants, of up to 10 MW, are the backbone of electricity production in many European Union (EU) countries today (EREC, 2010). It has also been the backbone of electricity production in New Zealand where 50% of their electricity supply has been from hydropower for decades (EECA, 2010). Fiji's energy demand was met by a diesel-based generators until its major hydro scheme at Monavasa in 1982 which saw a drop in imports by two-thirds and savings of up to $220 million between 1983 and 1991 (Yu & Taplin, 1998).

Biomass Energy

Biomass is another indirect expression of solar energy where the energy from the sun is captured by plants through the process of photosynthesis (Boyle, 2004). Biomass covers a wide range of products, by-products and waste streams derived from forestry and agriculture as well as from municipal and industrial waste streams (IEA, 2006). The final energy can be used for either heat, electricity or transport fuel through the many conversion pathways in existence today, from feedstock to final energy (EREC, 2010). Material such as firewood, rice husks and other plant or animal residues can simply be burned to produce heat which is what 'traditional biomass' is, and continues to make up a huge part of the energy consumption in many developing countries (Larkin, Ramage & Scurlock, 2004). Recently, 'new biomass' refers to materials which are processed on a large, commercial scale usually in developed countries to produce heat or any of solid, liquid or gaseous biofuels (Larkin *et al*., 2004). Solid, liquid or gaseous biofuels are the only renewable energy sources which have the potential to directly replace fossil fuels, either fully or in blends of various percentages (IEA, 2006). Energy from biomass, in the forms of fuelwood and agricultural residues, account for about 50% of total energy use in the Pacific Islands region of which two-thirds is used for domestic cooking in households and one-third used for heat and electricity by the industry sector (Yu & Taplin, 1998). Bioethanol and biodiesel make a contribution of 1.5% to the global road transport fuel demand (IEA, 2009). Most biofuels are expected to become competitive with cheap mineral oil products provided there is ample support from government by way of fuel tax exemptions or subsidies (Sims & Bassam, 2003).

A study conducted in the USA discovered that the biomass power generating industry employed more than 66,000 people and created more than $1.8 billion in personal and corporate income as well as generating more than $460 million in state and federal taxes (NREL, 1997). Biomass in the form of bagasse, which is the fibrous waste from sugarcane processing, is the largest source of renewable energy in Hawaii contributing 8% of its total electricity production (NREL, 1997). Today 61 MTOE[6] of biomass is used as final heat with firewood, chips, pellets and other by-products as raw materials; 9 Mtoe as electricity and 8 Mtoe as biofuels (EREC, 2010).

Geothermal Energy

Geothermal is the only form of renewable energy independent of the sun because its source is within the earth (Brown & Garnish, 2004) where temperatures of about 6000^{o}C exist (IEA, 2006). The attractive features of geothermal energy as a renewable source are its accessibility to both developed and developing countries, its low sulfur, CO_2 and other GHG emissions, its non-dependence on weather and season and is also not affected by fluctuations in exchange rates (IEA, 2006). Geothermal power is a commercially proven renewable resource which produced about 2% of the USA's renewable-source electric generating capacity in 1997 (NREL, 1997). Conventional geothermal electricity generation requires high temperature fields which is why this renewable resource is restricted to cities and towns located along active tectonic plate boundaries and on hot spots (IEA, 2006; IEA, 2009) such as New Zealand and Hawaii. New Zealand was one of the first countries to develop large-scale geothermal electricity generation in the 1950s and currently has over 600 MW of geothermal electricity generating capacity installed (EECA, 2010). Geothermal energy is considered to be the

[6] MTOE stands for mega-tonnes of oil equivalent (10^6 TOE)

best renewable option to meet the energy needs of Hawaii because a single 25 MW geothermal plant produces 19% of the baseload needs thus saving money by replacing 1000 barrels of imported fuel oil per day (NREL, 1997). Yu & Taplin (1998) believe there is potential for geothermal energy development in some of the Pacific Island countries. World electrical power generating capacity from geothermal resources by year 2000, had reached almost 8 gigawatts electrical (8 GW_e) and a further 16 gigawatts thermal (16 GW_t) for uses such as space heating, agriculture, aquaculture and a variety of other industrial processes (Brown & Garnish, 2004). Asmundsson (2008) carried out an assessment of geothermal energy and feasible utilization in the South Pacific Islands located between the Pacific Plate and the Australian-Indian plate, including Samoa, and discovered that geothermal energy is found widely in the region and there is potential for electricity production from geothermal energy.

Wave Energy

The oceans contain a mammoth amount of power which can be harnessed from different sources to generate useful energy (IEA, 2006). The World Energy Council estimated the global wave power resource to be 2 TW which is equivalent to an annual availability of an energy resource of 17,500 TWh (Duckers, 2004). Yu & Taplin (2008) believe that ocean thermal energy and energy from sea waves could become substantial resources for the Pacific Islands region. Similarly Duckers (2004) implies that wave energy offers a very large renewable resource potential for the United Kingdom (UK) to tap into. The distinctive advantages of wave power according to Twidell & Weir (2009) are the availability of large fluxes and the predictability of wave conditions over periods of days. However, compared to the other renewable technologies mentioned earlier, wave energy is still in its infancy stages of development (IEA, 2006) but similarly generates no greenhouse gas emissions like the others.

RESEARCH DESIGN

Samoa is still in its infancy stages of renewable energy development, which is why there is not much literature found on this subject. For this reason, it was decided by the writer that the focus of the research will be on the current renewable energy situation in Samoa, if any, and whether there is a future for this tiny Pacific Island developing nation in the world of renewable energy.

The data and information for the literature review were collected from online sources as well as textbooks used throughout the duration of the 'Master of Science in Renewable Energy' course. These internet searches yielded information pertaining to renewable energy in developing countries similar to Samoa. Furthermore, the online searches provided the writer with more insight into the current global renewable energy situation as well as that of the Pacific Island countries, scattered throughout the vast Pacific Ocean.

The required data and information on the state of renewable energy in Samoa was collected via emails with respective government ministry representatives as well as utilizing information available online from these government ministries' websites. Such emails were penned to obtain the necessary documents which may not have been found on the respective websites. No interviews were possible due to the time differences and the distance as well as the cost of phone calls between the two countries of Belgium and Samoa.

The acquired information and data were then analysed and compiled to produce this dissertation thesis on the state of renewable energy in Samoa.

Data and information on solar and wind energy in Samoa were collected from the Secretariat of the Pacific Regional Environment Programme (SPREP), EPC and a feasibility study carried out by Imo-Seuoti & Faasoa-Chan Ting (2009).

In 1986, Safotu, a village on the biggest Samoan Island of Savaii was electrified via the use of 30 PV panels where 25 were installed on homes while 5 panels were mounted on the Catholic church building (SPREP, 2004). The system used LX100GT 42 Wp[7] Solarex panels feeding a 12V 100 Ah @ C_{100} lead-acid storage battery through a discharge controller, no charge controller was included in the Solarex panels (SPREP, 2004). Furthermore, three high efficiency 13W fluorescent tube lights were also installed per household. Students from the local Polytechnic institution along with two villagers were trained for the installation and the whole village was trained in basic maintenance including the use of a voltmeter and a hydrometer for operational checks (SPREP, 2004).

The PV powered mini-grid system installed on the smallest inhabited Samoan volcanic caldera of Apolima in 2005, was a replacement for an ageing and expensive diesel generator. It provides electricity for 10 households and 1 church of about 100 residents. The PV design for Apolima has protection against high temperature, salty environment and high humidity

[7] Wp stands for watt-peak which is the amount of power generated when exposed to 1000 W/m^2 of solar radiation

as well as built-in redundancy to ensure the whole system does not crash should a component failure occurs. The PV design consists of 84 × 160 Wp modules for a total of 13.44 kWp[8] and four Outback 60A[9] Maximum Powerpoint Tracker (MPPT) controllers to ensure optimal battery charging (Wade, Langham, Jensen, Clay & Walter, 2008). In addition, there are five Outback model 2300VA[10] 230V 50Hz[11] inverters which provide up to 11.5 kW from the 48 VDC input (Wade *et al*., 2008). Wade *et al*. (2008) clarified that the Outback inverters are protected from the salt laden air of Apolima by having them sealed and the stacked inverter arrangement with associated control hub ensures continued operation at reduced capacity in case one or more inverters or charge controllers fail. Because Samoa is prone to cyclones, the design should be able to withstand high winds so the modules were mounted onto an array frame made from a treated pine columnar structure and Unirac aluminium mounting rails which were easily adapted to the sloping and uneven ground, at the same time allowing for secure mounting of the modules (Wade *et al*., 2008). The powerhouse is a well-ventilated cube of concrete with a shading wooden roof to keep the temperature inside the building as low as possible preserving battery life and protecting system electronics within (Wade *et al*., 2008; Imo-Seuoti & Faasoa-Chan Ting, 2009). The PV mini-grid system is located at 13.82^{o}S and 172.15^{o}W (Imo-Seuoti & Faasoa-Chan Ting, 2009) as shown in Figure 5 below.

[8] kWp stands for kilowatt-peak (10^3 Wp)
[9] 'A' stands for amperes of current
[10] VA stands for volts amperes
[11] Hz stands for hertz

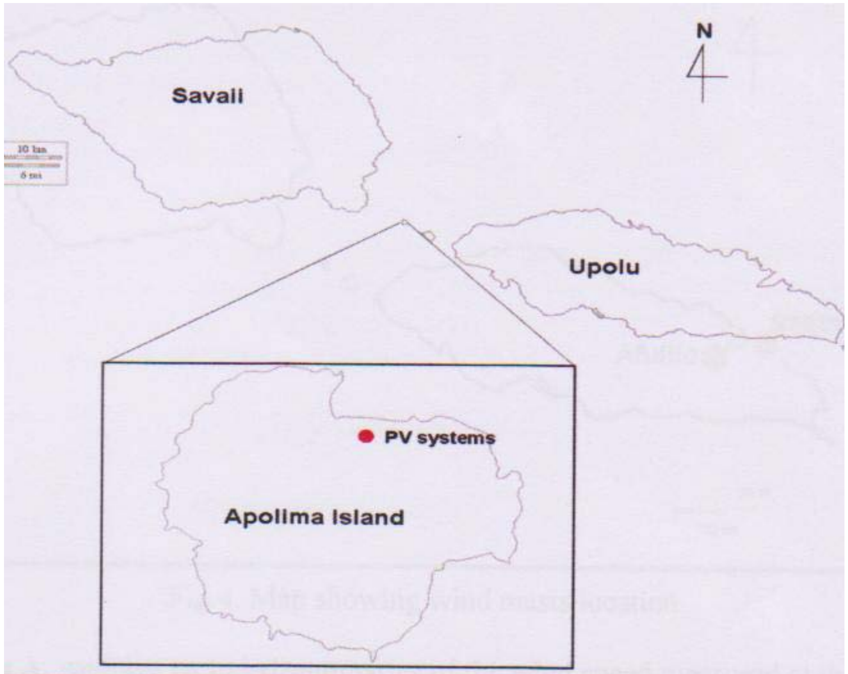


Figure 5: Map showing PV mini-grid system location on Apolima
(Source: Imo-Seuoti & Faasoa-Chan Ting, 2009)

Wind resource assessments have been carried out by EPC with the installation of two wind meteorological monitoring masts at the villages of Afulilo and Satitoa on Upolu Island. Both masts had thermocouples, anemometers and wind vanes with the latter two sensors recording readings every 10 minutes, from 2006–2008 (Imo-Seuoti & Faasoa-Chan Ting, 2009). The recorded data then is logged onto microchips which EPC later downloads onto a computer for analysis. The Afulilo mast had three anemometers at heights 10m, 20m and 30m while the Satitoa mast only had two anemometers at heights 10m and 30m (Imo-Seuoti & Faasoa-Chan Ting, 2009). Imo-Seuoti & Faasoa-Chan Ting (2009) carried out a feasibility study based on the data provided by EPC concentrating on consecutive monthly periods with full data sets as unforeseen technical problems experienced meant gaps in the data available.

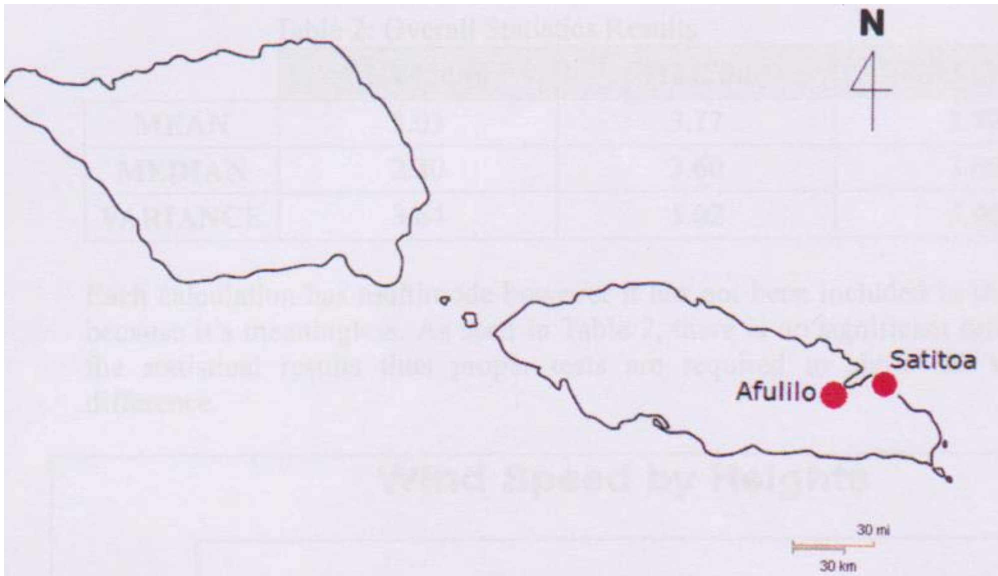


Figure 6: Map showing PV location of wind masts
(Source: Imo-Seuoti & Faasoa-Chan Ting, 2009)

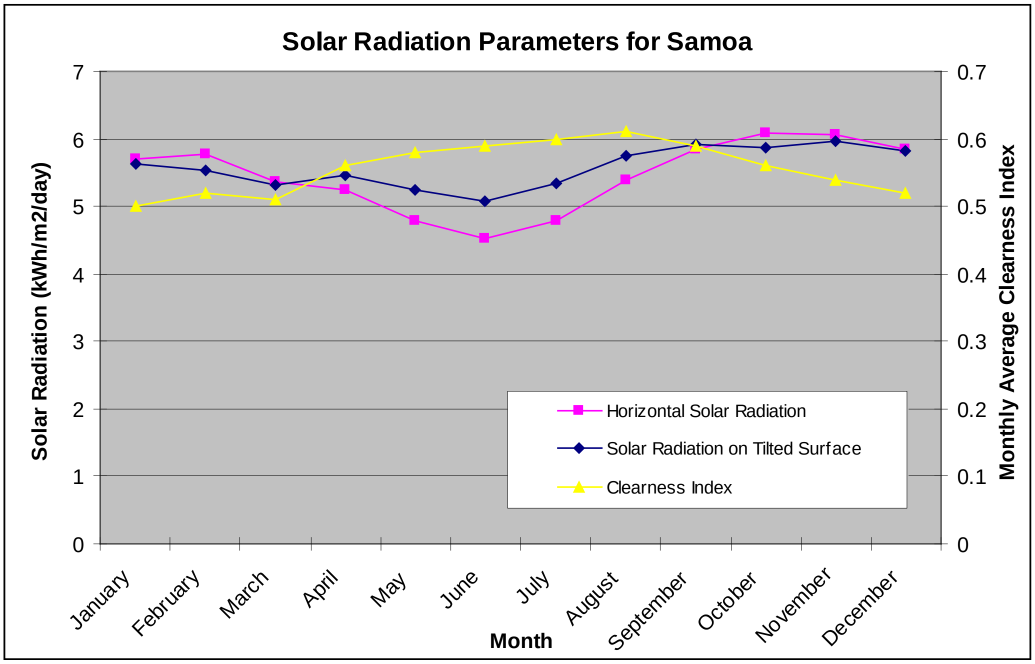
RESULTS

Solar Energy

The following parameters were obtained from the NASA Surface Meteorology and Solar Energy Data Centre which were calculated averages over 22 years, from July 1983 through to June 2005.

Table 2: Monthly Average Solar Radiation Values for Samoa (NASA)

Latitude 13° 35S Longitude 172° 20W	**Horizontal Solar Radiation (kWh/m²**/day)	**Solar Radiation on Tilted Surface (Slope = Latitude) (kWh/m²**/day)	**Clearness Index**
January	5.71	5.64	0.50
February	5.78	5.53	0.52
March	5.36	5.32	0.51
April	5.24	5.47	0.56
May	4.79	5.24	0.58
June	4.53	5.08	0.59
July	4.79	5.33	0.60
August	5.38	5.75	0.61
September	5.84	5.92	0.59
October	6.08	5.88	0.56
November	6.05	5.96	0.54
December	5.85	5.81	0.52
Annual Average	**5.44**	**5.58**	**0.56**



F*igure 7: Solar Radiation Parameters for Samoa*

The PV powered project in Safotu failed because there was lack of continuing support from EPC following a change in management, lack of spare parts locally compounded by villagers' lack of ability to communicate effectively with Solarex Australia and the training provided for system maintenance was insufficient (SPREP, 2004). In addition, families paid an installation fee of SAT $200 (approximately AUD $89) and were expected to make weekly payments of SAT $10 (approximately AUS $4.45) into a bank account for system maintenance and battery replacement (SPREP, 2004), but these funds were misappropriated. As a result, the PV system fell into disrepair and the village ultimately was connected to the grid.

On Apolima Island where the electricity is provided solely by a PV powered mini-grid system, its 100 residents have consistently been provided with grid quality power since commissioning in January 2007, without any power interruptions even throughout periods of two weeks without the sun (Wade *et.al*., 2008). In 2009, around 7.7 MWh of electricity was generated by the PV system (MOF, 2010). It was reported that since its operation, the PV mini-grid system has reduced Samoa's fuel consumption by 6000–7000 litres of fuel (Young, n.d.) saving EPC millions of tala.

The importation of solar hot water heaters (SHWH) increased from 2008 with 23 imported systems to 130 imported systems in 2009, mainly for the tourism infrastructure sector (MOF, 2010).

Solar energy is also used by many Samoans to dry their crops such as cocoa beans and copra, the former being more popular than the latter due to the lack of available market options with regards to the reduced copra oil companies in the country over the years.

Wind Energy

The following wind parameters for Samoa were obtained from the NASA Surface Meteorology and Solar Energy Data Centre which were calculated averages over 10 years from July 1983 through to June 1993.

Wind speed values in Table 3, were recorded at 50 m and 10 m (with terrain similar to that of an airport) above ground level and each monthly averaged value is evaluated as the numerical average of 3-hourly values for the given month.

Average temperature values also shown in Table 3, were calculated based on values for each month over a 22-year period from January 1983 to Dec 2004.

Table3: Recorded Parameters for Wind Resource Assessment (NASA)

Latitude 13^o 35S Longitude 172^o 20W	**Monthly Average Wind Speed at 50 m (m/s)**	**Monthly Average Wind Speed at 10 m (m/s)**	**Monthly Average Temperature (^{o}C)**
January	4.86	4.16	29.1
February	5.36	4.58	29.3
March	4.90	4.19	29.4
April	5.01	4.29	29.4
May	5.92	5.05	29.0
June	6.66	5.69	28.5
July	7.18	6.14	28.0
August	7.26	6.21	27.7
September	6.87	5.87	27.9
October	6.18	5.28	28.3
November	5.38	4.59	28.8
December	5.19	4.44	29.1
Annual Average	**5.90**	**5.04**	**28.7**

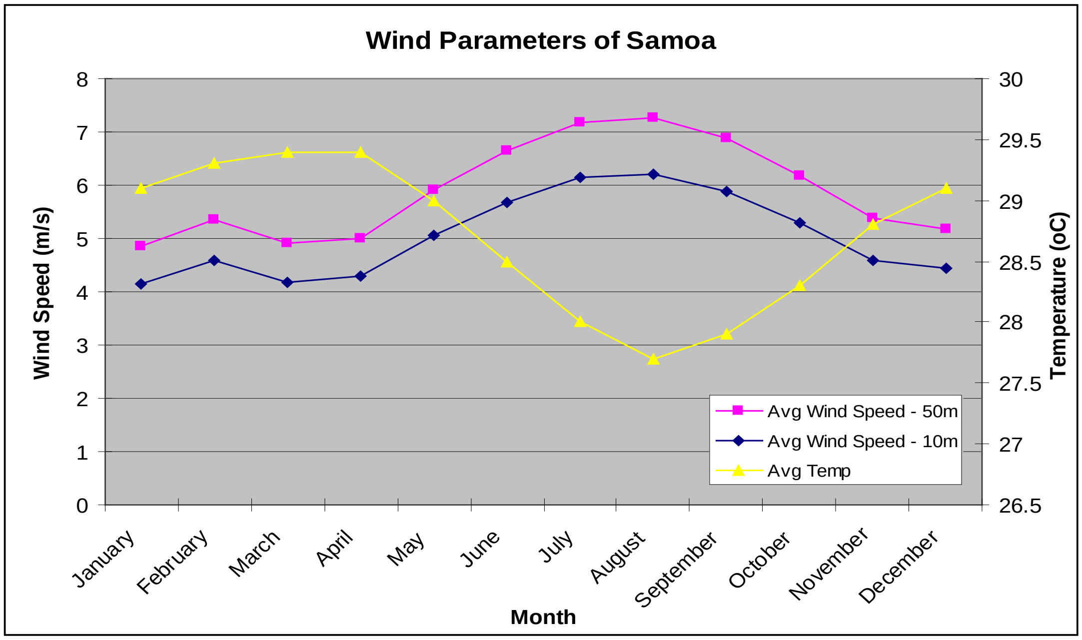


Figure 8: Wind & Temperature Parameters for Samoa

The following wind data for Samoa was obtained from a feasibility study carried out by Imo-Seuoti & Faasoa-Chan Ting (2009), and values were calculated averages over 16 months from November 2006 – February 2008 for the Afulilo site whereas averages for the Satitoa site were calculated over a 13-month period from June 2007 to June 2008.

Wind speed values in Table 4, were recorded at 10 m, 20m and 30 m above ground level at Afulilo. Each monthly averaged value is the numerical average of 10-minute values for the given month (Imo-Seuoti & Faasoa-Chan Ting, 2009).

Table4: Afulilo Wind Speed Averages (Imo-Seuoti & Faasoa-Chan Ting, 2009)

Month & Year	**Monthly Average Wind Speed at 10 m (m/s)**	**Monthly Average Wind Speed at 20 m (m/s)**	**Monthly Average Wind Speed at 30 m (m/s)**
Nov. 06	3.56	4.27	4.45
Dec. 06	2.28	2.76	2.81
Jan. 07	3.44	3.99	4.00
Feb. 07	2.06	2.60	2.58
Mar. 07	2.10	2.82	2.77
Apr. 07	2.52	3.12	3.12
May 07	2.87	3.50	3.42
Jun. 07	4.08	4.88	4.95
Jul. 07	3.86	4.69	4.70
Aug. 07	4.47	5.44	5.49
Sep. 07	3.74	4.59	4.58
Oct. 07	2.81	3.36	3.31
Nov. 07	2.52	3.37	3.41
Dec. 07	2.74	3.49	3.56
Jan. 08	3.03	4.04	4.11
Feb. 08	2.68	3.61	3.69
Monthly Average	**3.05**	**3.78**	**3.81**

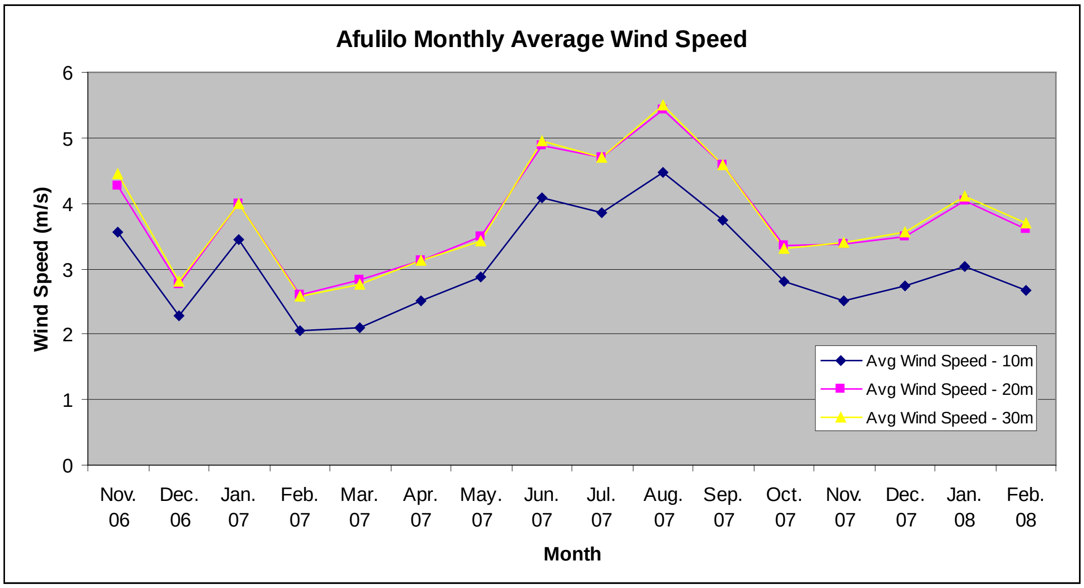


Figure 9: Afulilo Monthly Average Wind Speeds

Wind speed values in Table 5 shows readings taken at 10m and 30 m for Satitoa. Each monthly averaged value is the numerical average of 10-minute values for the given month (Imo-Seuoti & Faasoa-Chan Ting, 2009).

Table5: Satitoa Wind Speed Averages (Imo-Seuoti & Faasoa-Chan Ting, 2009)

Month & Year	**Monthly Average Wind Speed at 10 m (m/s)**	**Monthly Average Wind Speed at 30 m (m/s)**
Jun. 07	0.40	6.38
Jul. 07	0.40	5.55
Aug. 07	0.40	6.29
Sep. 07	0.40	4.91
Oct. 07	1.09	3.91
Nov. 07	3.32	3.88
Dec. 07	3.76	4.27
Jan. 08	4.15	5.01
Feb. 08	3.41	3.90
Mar. 08	3.33	3.91
Apr. 08	3.30	3.80
May 08	3.24	3.82
Jun. 08	5.33	5.86
Monthly Average	**2.50**	**4.73**

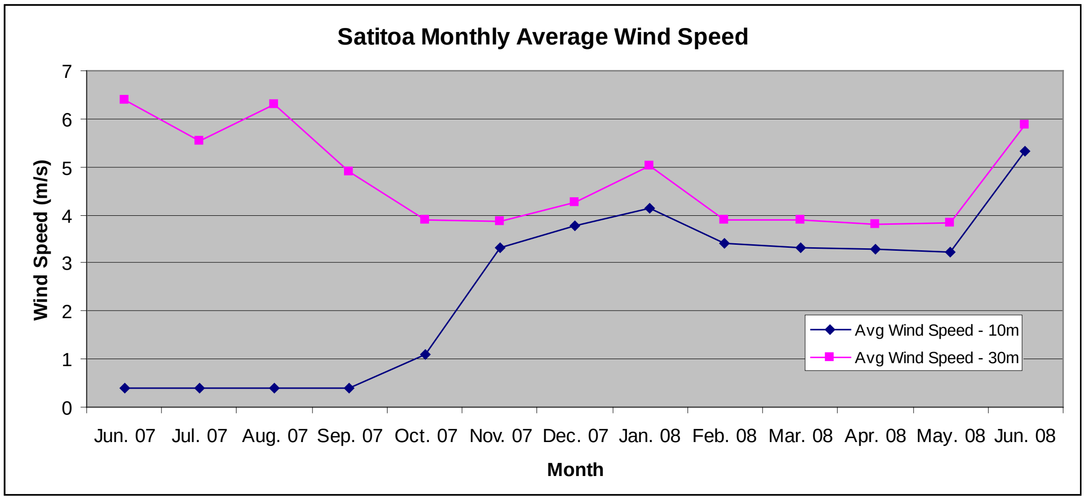


Figure 10: Satitoa Monthly Average Wind Speeds

Wind speed values in Table 6 are readings from the 20m and 30m masts at Afulilo as well as the 30m mast at Satitoa, for the common months of June 2007 to February 2008. Each monthly averaged value is the numerical average of 10-minute values for the given month (Imo-Seuoti & Faasoa-Chan Ting, 2009).

Table6: Wind Speed Averages at 20m & 30m for Afulilo & Satitoa (Imo-Seuoti & Faasoa-Chan Ting, 2009)

	AFULILO		SATITOA
Month & Year	**Monthly Average Wind Speed at 20 m (m/s)**	**Monthly Average Wind Speed at 30 m (m/s)**	**Monthly Average Wind Speed at 30 m (m/s)**
Jun. 07	4.88	4.95	6.38
Jul. 07	4.69	4.70	5.55
Aug. 07	5.44	5.49	6.29
Sep. 07	4.59	4.58	4.91
Oct. 07	3.36	3.31	3.91
Nov. 07	3.37	3.41	3.88
Dec. 07	3.49	3.56	4.27
Jan. 08	4.04	4.11	5.01
Feb. 08	3.61	3.69	3.90
Monthly Average	**3.78**	**3.81**	**4.90**

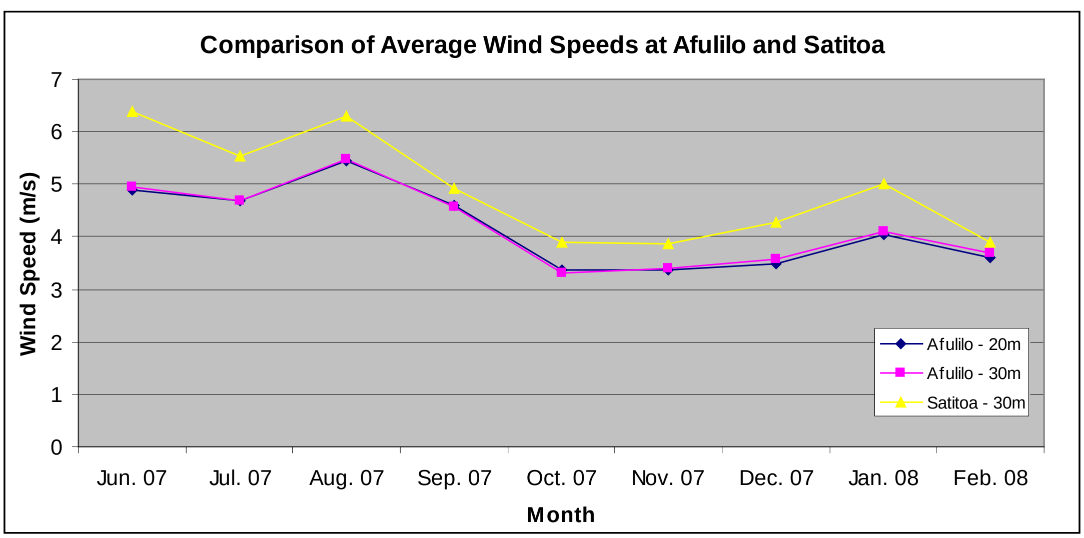


Figure 11: Satitoa Monthly Average Wind Speeds

Below are Figures 12, 13 & 14 showing the frequency histograms of wind speeds recorded by EPC for Afulilo at 20m and 30m as well as 30m at Satitoa. This was not done for height 10m at both sites as the data was considered not feasible due to very low average wind speed values (Imo-Seuoti & Faasoa-Chan Ting, 2009).

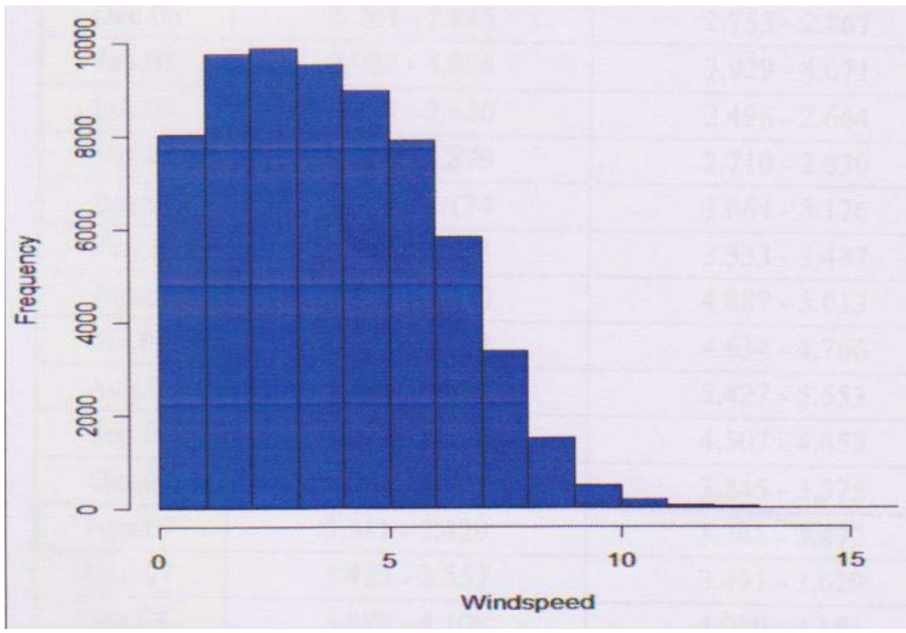


Figure 12: Frequency Histogram of Wind Speeds at Afulilo (20m)
(Source: Imo-Seuoti & Faasoa-Chan Ting, 2009)

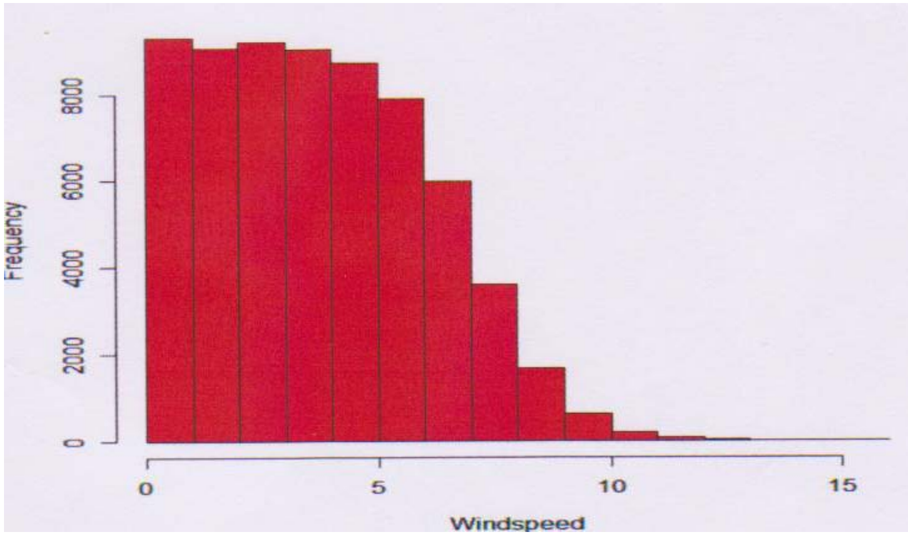


Figure 13: Frequency Histogram of Wind Speeds at Afulilo (30m)
(Source: Imo-Seuoti & Faasoa-Chan Ting, 2009)

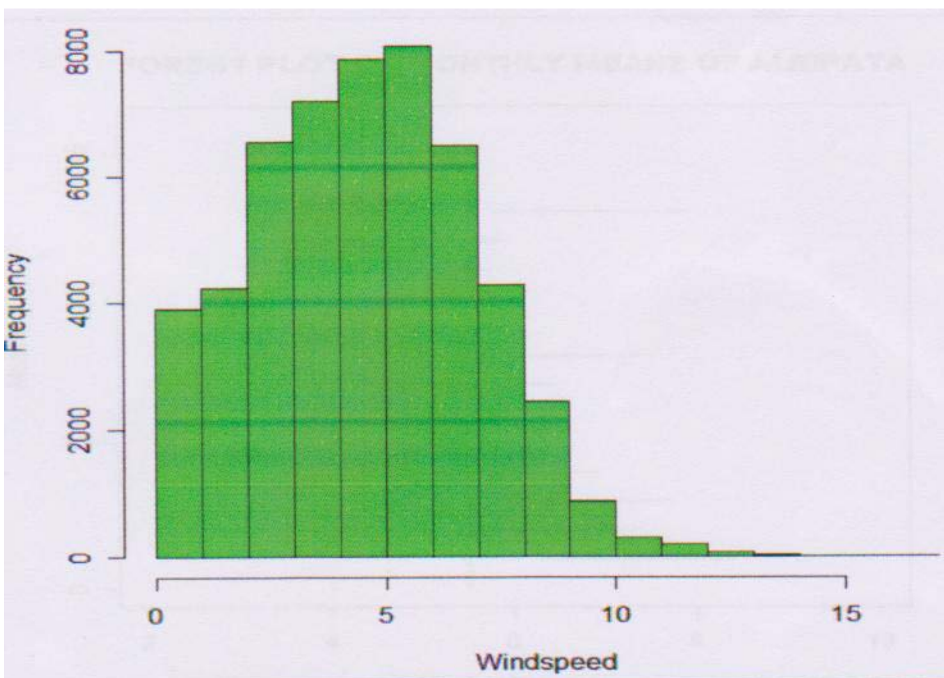


Figure 14: Frequency Histogram of Wind Speeds at Satitoa (30m)
(Source: Imo-Seuoti & Faasoa-Chan Ting, 2009)

Figure 15 is a map of wind speeds by Garrad Hassan (n.d.), recorded at 55m above ground level for the island of Upolu where the two earlier mentioned masts were installed.

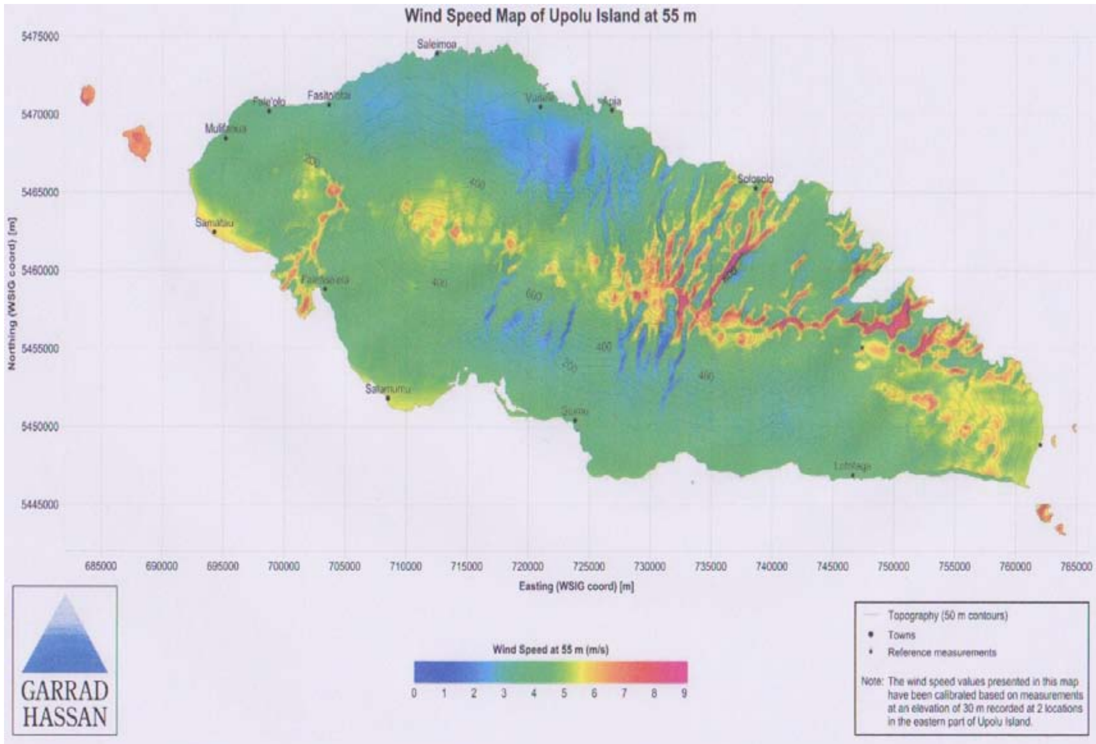


Figure 15: Wind Speed Map of Upolu Island at 55m above ground level
(Source: Young, n.d.)

Hydropower

Currently the reservoir at Afulilo (Figure 6) with small run-of-river hydro stations at Alaoa, Fale-o-le-Fee, Samasoni and Lalomauga on Upolu Island (EPC, 2007) contribute an average of 40% of the total electricity supply in the form of hydropower (MOF, 2010; EPC, n.d.). The Afulilo reservoir is Samoa’s largest single hydro capacity of 4 MW (EPC, 2007). In

2009, energy from hydropower accounted for 3.8 kTOE[12] or 159 TJ[13] of energy (MOF, 2010).

It has been reported that seven sites in six villages on both Savaii and Upolu islands have been identified as potential hydropower sites for more small run-of-river schemes (Young, n.d.).

Biomass

Biomass in the form of firewood, wood charcoal, coconut shells and husks, is used mainly in Samoa by the residential sector for household cooking. It is the most consumed renewable energy source on the islands (Figure 2).

In 2005, EPC operated one of its generators at the Salelologa Power Station on the biggest Samoan Island of Savaii, using a blend of 10% coconut oil with 90% diesel (EPC, 2007) which proved successful. More success followed in 2009 when EPC ran three of its four diesel generators at their Tanugamanono Power Station on Upolu Island, on a blend of 5% coconut oil and 95% diesel.

Currently, two government corporations namely EPC and SROS are running a couple of their vehicles each, on coconut oil / jet fuel blends and so far are running smoothly.

[12] kTOE stands for kilo-tonnes of oil equivalent (10^3 TOE)
[13] TJ stands for tera-joules (10^{12} J)

SROS is currently undertaking research into producing biodiesel from coconut and jatropha to replace fossil fuels used in transport and electricity production (SROS, n.d.).

Geothermal

There is presently no geothermal activity in Samoa. However, Asmundsson (2008) carried out an assessment of geothermal energy and feasible utilization in the South Pacific Islands including Samoa, and discovered that there might be geothermal hot spots below the surface because of three volcano eruptions in past years (1760, 1902 and 1905-1911), despite having no hot springs in Samoa.

Wave

Identical to geothermal energy, there is currently no utilization of the energy from the waves, despite being surrounded by ocean. Nonetheless, Oceanor which was a company from Norway mapped this resource (wave heights, wave speed and wave energy) for Samoa using data buoys moored off the shores of Upolu Island (SPREP, 2004). The results (Figure 16) revealed that in the open sea, annual mean wave power levels are in the region of 20–25 kW/m[14], south coast of Upolu yielded a long term average of about 16 kW/m while the northern shores averaged 8–9 kW/m (SPREP, 2004).

[14] kW/m is the amount of power generated per meter of wave in kilowatts per metre

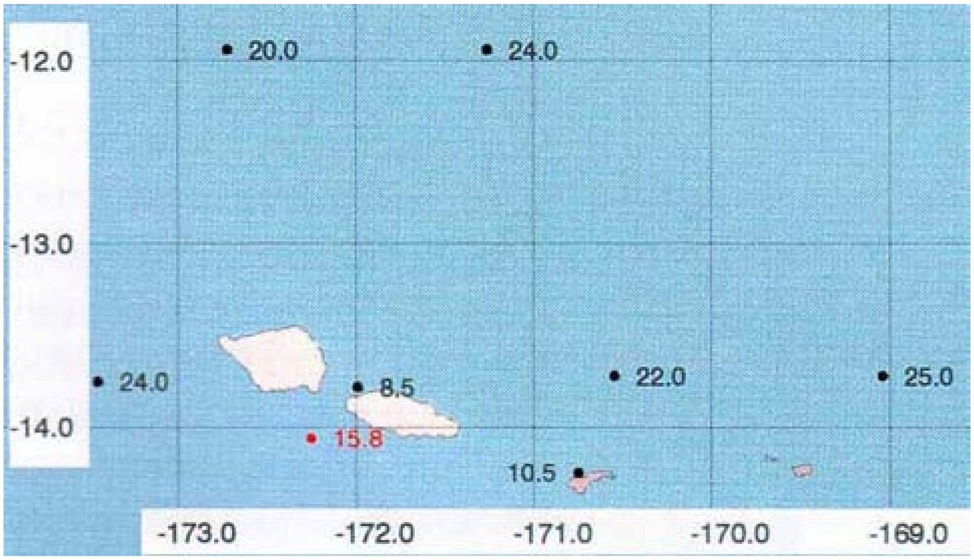


Figure 16: Wave Energy Map of Samoa
(Source: Oceanor (n.d.) in SPREP (2004))

INTERPRETATION OF RESULTS

Solar Energy

The amounts of solar radiation incident on both horizontal and tilted surfaces (Table 2) are a clear indication that Samoa has an excellent resource in solar energy because annual average solar radiation values on both surfaces are greater than 5 kWh/m^2/day. The lowest monthly average of 4.53 kWh/m^2/day received in June was greatly increased to 5.08 kWh/m^2/day by tilting the surface, indicating significant seasonal effects. However this is not a major factor considering the more uniform values achieved by tilting the surface to produce adequate amounts of solar radiation received throughout the whole year. Furthermore, the Clearness Index values in Table 2 and Figure 7 plainly point to “clear skies” most of the year further cementing the fact that Samoa has an absolutely tremendous amount of solar energy (Yu & Taplin, 1998; Dornan, 2010) it can utilize to satisfy its energy needs. Hence, there is sufficient solar energy for commercial and domestic water heating as well as for household electricity generation (SPREP, 2004). Therefore the use of already installed solar water heaters and most importantly the success of the PV mini-grid system on Apolima Island should be seen as the launch of a solar-powered Samoa in the future. Lessons learnt from the failure of the Safotu PV system have helped to ensure the success of the Apolima Island PV mini-grid system whereby all repairs and maintenance works are carried out by qualified EPC personnel and any equipment replacements have been free of charge because the system is still under warranty (Young, n.d.). The availability of an excellent solar resource along with experiences gained so far from the Safotu and Apolima projects provide for an extremely positive outlook on EPC's mission to provide electricity to the remaining 5% of the Samoan population without access, through rural electrification. However, due to the initial costs involved with such projects, financial assistance is much needed in order for this plan to come to fruition (Young, n.d.).

Solar heating has been proven successful in Samoa over the last 20 years (MOF, 2007) and is the cheapest option used commercially by the tourism sector, hotels especially, to reduce their costs in producing hot water. Household water heating can also be achieved the same way, but initial system costs coupled with the fact that bathing in Samoa is traditionally in cool water, have contributed to very little market demand for household solar hot water systems. Solar energy has long been used by Samoans for drying crops and this practice will continue to be the cheapest way for drying Samoan crops such as cocoa beans and copra.

Wind Energy

It is obvious from the graphs (Figures 8, 9 and 10) comparing average wind speeds at the different wind mast heights that the wind speed increases with increasing wind mast height (Manwell, McGowan & Rogers, 2008; Twidell & Weir, 2009). There is a positive correlation between wind speed and height above ground (Imo-Seuoti & Faasoa-Chan Ting, 2009; Twidell & Weir, 2009) which is known as 'wind shear'. The results provided by Imo-

Seuoti & Faasoa-Chan Ting (2009) are more realistic than the ones provided by NASA (n.d.) especially for the 10m height because the former used data which was actually measured on site by EPC whereas NASA readings are taken via satellite. Such conditions as terrain, roughness and specific obstacles have to be taken into account when considering a wind turbine site which may not be accurately recorded from where satellites rotate. Of the two wind masts set up at Afulilo and Satitoa, it is obvious from Figure 11 that Satitoa is a better site than Afulilo because average monthly wind speeds for 30m were much higher for Satitoa than those of Afulilo. Wind speed values recorded at 10m were disregarded because they were considered non-feasible with low average wind speeds due to the fact that this height is where obstacles such as buildings, trees and telecommunication towers can decrease wind speeds considerably (Tables 4 and 5) so there will not be enough wind to produce any wind-power (Whale, 2010). It is for this same reason the values obtained from the Satitoa mast, located along the coast were much higher than the Afulilo mast installed on a hilltop because the smoother surface of the open waters provided least resistance compared to obstacles on the hill (Imo-Seuoti & Faasoa-Chan Ting, 2009). Moreover, a minimum wind speed of 6.5 m/s at 30m is essential for sufficient electricity production at a wind farm (Whale, 2010) which deems both sites as non-feasible for large scale wind power production because all the monthly wind speed averages were all below this minimum limit. In addition, the frequency histograms (Figures 12, 13 and 14) reveal that the most common wind speeds were 2–3 m/s and 5–6 m/s at Afulilo and Satitoa respectively which rules out Afulilo as a potential wind power production site. Wind speeds at Satitoa may be just enough for a lone turbine to cater for one household but not feasible for a wind farm. However, Figure 15 assures that there are areas on Upolu with wind speeds of 6–8 m/s at height 55m which will be ideal spots to set up wind farms.

Hydropower

This is the second highest contributor of renewable sources to energy production in Samoa making up 40% of the grid on Upolu Island. This value can increase if hydropower is also introduced to the Savaii power system which is entirely diesel-based to this day. Several studies have been carried out on the potential of hydropower in Samoa and results revealed that a three phase cascade development of hydro can be installed at the Sili River basin on Savaii Island as well as introducing more small run-of-river hydro stations (Young, n.d.) similar to the existing ones, which will significantly boost the contribution of hydropower to electricity production in Samoa (SPREP, 2004). By so doing, the total expenditure costs to EPC will be greatly reduced as a result of less fossil fuel purchased, because Twidell & Weir (2009) believe that the potential for hydro generation from run-of-river schemes has often been underestimated. The main restrictions on recent hydropower initiatives in Samoa were access to appropriate natural water resources in addition to funding limitations (MOF, 2007).

Biomass

This is the most common form of renewable sources found on island, and will continue to be the case because a lot of the domestic cooking especially in the rural areas, is carried out in outside kitchens using firewood, charcoal, coconut husks and shells. Moreover, the abundance of biomass due to favorable tropical conditions means that the 106,600 hectares of Samoan land covered with forests according to a study by Leavasa & Pouli in 2000 (SPREP, 2004) will be an ample supply of this renewable resource.

An Agricultural Census carried out in 1999 (SPREP, 2004) revealed that about 53,200 hectares of land on both Savaii and Upolu were under coconut and most of them are still within their economic bearing age of 60 years or under. Thus there is an abundant supply of coconuts on island for the production of coconut oil and its esters to replace fossil fuels, either as 100% oil or as a blend for distillate for power generation and transport (SPREP, 2004). This is encouraging for EPC and SROS who are currently carrying out trials on the use of coconut oil blends for electricity production and transport. However, the process of completely substituting fossil fuels with biofuels may not be realized over a long period of time in Samoa. The production of biofuels is still in its infancy stages.

Being the most common source of renewable sources, there is a real future in energy from biomass as discovered by a team from Imperial College, University of London in 2003 who disclosed several promising sources and technologies for Samoa to produce heat, electricity and liquid fuel from wood waste, agriculture waste and copra (SPREP, 2004).

Geothermal

Despite not having any geothermal activity at the moment, SPREP (2004) disclosed in a report that because the biggest island of Samoa resembles Hawaii in its formation and makeup, a basaltic shield volcano of young geologic age with an active volcanic rift system, there must be potential for a 4–5 MW geothermal power plant. Based on the findings of SPREP (2004) and Asmundsson (2008), it can be concluded then that the unknown geothermal potential in Samoa is promising, especially for the big island of Savaii.

Wave

The coastal power values for Samoa shown in Figure 16, which are more significant in harnessing this resource, were drastically lower so not much energy can be extracted because according to SPREP (2004), areas producing 10 kW/m at 25% efficiency would require 400 metres of wavefront for an average annual output of one megawatt (1 MW). Despite the high potential of waves to produce energy, it is highly unlikely that Samoa will act upon it (SPREP, 2004) due to the high costs of the equipment needed as well as the fact that Samoa is prone to cyclones every year making this venture even more expensive (Twidell & Weir, 2009) if it were taken up by the government.

CONCLUSION

Summary

All the data and information gathered for this dissertation from the various assessments and feasible studies undertaken by others, have indicated that the best options for renewable energy in Samoa are hydro, solar and biomass, followed closely by wind. Solar and wind power generate no greenhouse gas emissions and when such systems are properly managed, benefits will include clean energy, low maintenance and running costs as well as security of supply. Samoa having an excellent solar resource coupled with the success of the current PV powered mini-grid on Apolima means the remaining 5% of the population with no electricity access can soon expect to improve their livelihoods via EPC's rural electrification project. This can be expanded into grid-connected electricity from solar energy in due time, which will eventually save EPC and the government of Samoa millions of tala[15] from having to import costly fossil fuels for electricity production. Wind can also play its part in achieving one of the goals of the Samoa National Energy Policy Framework by making its contribution to increasing Samoa's contribution of Renewable Energy for energy services and supplies by 20% by year 2030. This is because the results of the wind feasibility study (Imo-Seuoti & Faasoa-Chan Ting, 2009) allude to the availability of this resource for power production, provided the masts are set up at the right sites without too many obstacles interfering with wind flow. Biomass dominates the renewable resources available in Samoa so there is a high possibility of

[15]'tala' is the Samoan currency which can be translated in English to 'dollar'

substituting fossil fuels by coconut oil for electricity production and transport, because Samoa has an abundant supply of coconuts for this purpose. Hydropower is already a major player on the electricity production scene in Samoa but there is still more to be extracted from other hydro sites on Upolu and Savaii.

On the other hand, funding is always a limiting factor in all of the mentioned energy-extracting projects and Samoa being a tiny developing island in the Pacific, depends heavily on aid from overseas countries and organisations to fund most of its planned development projects. For this reason, geothermal and wave may be promising but undertaking feasibility studies for these resources at present, may not prove a worthwhile investment.

Funding is available from a number of energy agencies and international organisations such as IRENA, European Union (EU), AusAID, SOPAC, United Nations Development Programme (UNDP), PIGGAREP, SPREP, Intra-ACP Funding under the Cotonu agreement under the development corporation between EU and the Asian Carribean Pacific (ACP) countries, to name a few. Funding has also been directed to Samoa for various other projects from countries such as China, Japan, Australia, New Zealand, Canada, Italy, Austria, Turkey and many others who will only be too willing to fund worthwhile renewable energy projects they know will make a difference in the lives of Samoan villagers who are currently without or with very limited access to electricity.

The ongoing support by government also plays a vital role in ensuring any project is successfully implemented and carried forward. Through this support, adequate training for those involved in maintaining the various renewable energy systems can be provided so that these personnel are well-equipped with the knowledge and skills required to succeed.

Recommendations

Based on the information gathered thus far for this dissertation, it is recommended that a rural electrification feasibility study be carried out to determine the exact number of people without electricity access and their insolation levels so the right systems (correct PV & batter sizing, load profiles, etc) are matched up with the right people. For wind, it is desirable to carry out more wind assessments (wind speeds, direction, etc) on some other sites on both Upolu and Savaii islands so the right locations are chosen to enable EPC to tap into this renewable source. For more small run-of-river schemes to be established, careful assessments need to carried out prior to any installation to determine the amount of power produced. More in-depth analysis of the estimated power generated from each of the above resources is to be carried out at the chosen sites, sound financial investment plans to be formulated before seeking financial aid.

It is also recommended that research and experimentation be carried out on other available oil-producing sources in Samoa so biofuel production is not heavily reliant on coconut which may affect the food supply as this is one of the important food products in the Samoan way of life.

Geothermal and ocean energy need concrete evidence from more data collection to determine the feasibility of these two resources.

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